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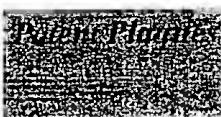
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## WO101206A2: SYSTEM DYNAMICS MODEL BUILDER AND SIMULATOR

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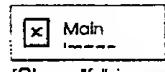
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Abstract:

A system dynamics modeling environment has a graphical user interface to allow a model developer to define a model through graphical inputs, for example by selecting icons and dragging them onto a representation of a flow diagram. The data and other information regarding a particular model are stored within a database structure that efficiently organizes the data. A second non-graphical editor is provided as a separate and distinct tool for editing the equations and other information representative of a model. The system dynamics modeling environment allows the definition of a plurality of groups, with each group consisting of a data set representing a complete flow diagram and capable of being coupled to another group defining a portion of the model on the same layer of the model. An efficient simulation environment is provided that determines which groups within a model are active and performs simulations only on those active groups. Users will also have the ability to create customized user interfaces, or "dashboards" for their models, without requiring programming experience. Users also have access to features that make it easy to create and save scenarios and models.

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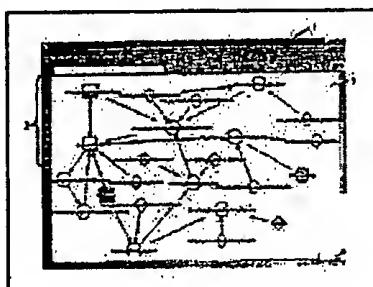


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## Abstract

A system dynamics modeling environment has a graphical user interface to allow a model developer to define a model through graphical inputs, for example by selecting icons and dragging them onto a representation of a flow diagram. The data and other information regarding a particular model are stored within a database structure that efficiently organizes the data. A second non-graphical editor is provided as a separate and distinct tool for editing the equations and other information representative of a model. The system dynamics modeling environment allows the definition of a plurality of groups, with each group consisting of a data set representing a complete flow diagram and capable of being coupled to another group defining a portion of the model on the same layer of the model. An efficient simulation environment is provided that determines which groups within a model are active and performs simulations only on those active groups. Users will also have the ability to create customized user interfaces, or "dashboards" for their models, without requiring programming experience. Users also have access to features that make it



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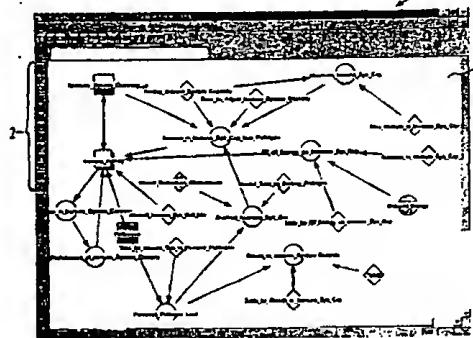
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(57) Abstract: A system dynamics modeling environment has a graphical user interface to allow a model developer to define a model through graphical inputs, for example by selecting icons and dragging them onto a representation of a flow diagram. The data and other information regarding a particular model are stored within a database structure that efficiently organizes the data. A second non-graphical editor is provided as a separate and distinct tool for editing the equations and other information representative of a model. The system dynamics modeling environment allows the definition of a plurality of groups, with each group consisting of a data set representing a complete flow diagram and capable of being coupled to another group, defining a portion of the model on the same layer of the model. An efficient simulation environment is provided that determines which groups within a model are active and performs simulations only on those active groups. Users will also have the ability to create customized user interfaces, or "dashboards" for their models, without requiring programming experience. Users also have access to features that make it easy to create and save scenarios and models.

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**PRIORITY:**

15 This application claims priority from U.S. provisional patent application Serial No. \_\_\_\_\_, filed June 30, 1999, which application is hereby incorporated by reference in its entirety.

**BACKGROUND OF THE INVENTION**20 1. **Field of the Invention**

The present invention relates to systems, methods and products for developing and executing system dynamics models.

2. **Description of the Related Art**

System dynamics and system dynamics modeling provide tools for analyzing complex systems. For example, system dynamics modeling has been applied to biological systems including the production and regulation of insulin within a human body, to educational processes including modeling how students learn, to social systems 5 including modeling the relationship between crime and drug availability, and to a variety of economic and business situations. By applying the principals of system dynamics, computational models with qualitative and, often, quantitative accuracy can be developed and can be used to gain an understanding of the modeled system. Even when a model is highly schematic, insights can be drawn simply because the system dynamics model 10 adequately represents the structure and relationships among elements of a system. Causal relationships that are not evident in a static model can become apparent in a system dynamics model.

Once an accurate system dynamics model is developed, the model can be used to perform computer-based experiments and simulations to evaluate changes in structure 15 and in the coupling between structures, and how varying the initial conditions or input variables affect the system. For example, control mechanisms such as rules or policies can be tested on a system dynamics model to determine if the control will have the desired effect and whether the control is likely to be cost effective or advantageous.

What has allowed system dynamics modeling to be applied to such diverse 20 problems is the generality of the system dynamics methodology. In developing a system dynamics model, a model developer breaks down the system or problem to be analyzed into constituent elements and defines the relationships among the various elements of the system or problem. To the extent possible, the model developer attempts to define a

model in terms of fundamental constituent elements so that the model is as simple as possible while still having an appropriate level of structural detail. One way in which fundamental elements can be characterized is by identifying the minimum set of variables that describe the system. The relationships among the fundamental elements are 5 translated into the relationships among the variables that describe the system.

Relationships between any two elements can be defined functionally, that is in the form of an equation, or empirically, for example using a table listing an observed set of relationships.

Within the system dynamics literature, variables that describe the state of the 10 system are sometimes referred to as "stocks" or "levels" and the relationships between levels are defined in terms of "flows" or "rates." Another concept typically included in system dynamics models is that of an "auxiliary," which receives input data and converts or manipulates that input data to provide output data. "Connectors" are often used to illustrate graphically the flow of information among stocks, flows and auxiliaries.

15 One fundamental aspect of system dynamics is the explicit consideration of time in the model. Most all of the relationships among variables are time varying, which is a characteristic of system dynamics modeling that allows its models to represent real world systems. Simulating a system dynamics model causes the model to advance through a series of time steps, with many of the variables changing with each time step. Because 20 time is explicitly considered along with the relationships among different variables, feedback and environmental effects are an important aspect of system dynamics models. Using a system dynamics model allows the impact of changes in a variable to be observed, whether to evaluate the accuracy of a model or to understand the impact that

changes in the system variables have on the system as a whole. Graphs of system variables allow aspects of the system to be monitored, illustrating both transient behavior and steady state behavior, if it exists.

System dynamics models present a multivariable view of a system, focusing both 5 on the constituent elements of the system and the interaction among those elements. Variables interact with one another due to a variety of feedback mechanisms, causing the values of the variables, and thus the response of the system as a whole, to change over time. Instead of focusing on the independent activity of isolated sub-units, system dynamics attempts to model the structure of the entire system, the interaction among 10 variables in the structure and the way that this interaction changes the variables over time. In this way, the behavior of complex systems can be modeled as a function of time to provide a tool for understanding the system. Further, analysis of structural changes in part of the system can be observed to determine their effect on the system as a whole.

Conventional model optimization is prescriptive, in that an initial goal is set and 15 the model is tested under various conditions. The set of conditions that comes closest to the predetermined goal is deemed to be the "optimal solution." On the other hand, system dynamics simulations tend to be more descriptive, in that the initial conditions are set and the computer determines what would happen to the system over a particular time interval. System dynamics simulations are thus far more often "what-if" models. This 20 does not necessarily preclude system dynamics models from being used for forecasting discrete events. Developing a validated, predictive system dynamics model capable of such prediction requires a significant level of testing, observations and adjustments to

reach accuracy. Once such a model is developed, though, it can be used to predict system response with good reliability.

- A system dynamics model typically represents a set of linear and non-linear relationships among variables, with many of the relationships mathematically defined as differential equations or difference equations. These equations are integrated over time to generate a simulation. Stepping or cycling the model through time conventionally requires that all of the equations that make up the model be approximated or solved in each time interval or step. The complexity of these models requires the use of computers to fully understand the effect of changes to all but the very simplest of systems.
- 10 Consequently, system dynamics models are implemented in computer systems, with complex models testing the limits of conventionally available computer systems.

Construction and simulation of system dynamics models involves: (i) developing a model structure that is representative of the physical system relevant to the problem, including defining the variables that are representative of the system, (ii) defining the behavior of variables in the system, which are essentially a set of decision-making rules, (iii) setting initial conditions for the variables of the model, (iv) running the simulation for a specified time period or number of cycles to determine the overall change in behavior of the system, (v) testing the model by comparing it to observations, and (vi) modifying the model, as required. Tests of the model determine its validity or relevance and hence its usefulness. Tests might include model causal tests and model behavior tests. For instance, if a simulation of a population model shows a negative living population level when run for a particular time period, the model needs to be adjusted because it produced an outcome that is not physically possible.

In developing a system dynamics model, the boundaries of the system to be modeled are established to encompass the identified problem. Defining the boundaries of the problem is significant, in that the model developer selects structures and functions to include as being determinative of system behavior and selects other structures and 5 functions not to include because they are not sufficiently important. The structures and functions to be modeled are associated with variables and relationships. Because system dynamics models tend to be computationally intensive, it is preferable to tailor the model precisely while still leaving sufficient detail to accurately represent the system. The result of this model conceptualization stage may be a simplified flow or causal loop 10 diagram representing the variables of a system with their interrelationships.

Next, the diagram is translated into a computer useable form. This is generally accomplished with a program specifically developed for system dynamics modeling. When model definition produces a flow diagram, translating the model into a computer executable model is most easily accomplished through a graphical user interface. There 15 are presently a few software products for system dynamics model construction and simulation on the market that provide a graphical user interface in which a flow diagram can be entered graphically in a workspace so that the flow diagram is reproduced on the screen of a computer. For instance, "STELLA" (System Thinking Educational Learning Lab with Animation) available from High Performance Systems, Inc., Powersim 20 "Constructor" from Powersim, and "VENSIM" from Ventana Software are examples of icon-driven system dynamics modeling tools. These programs allow a model developer to define a system dynamics model in terms of a flow diagram entered into the computer graphically. STELLA, and to a lesser extent, Powersim Constructor, are designed

primarily to support the construction and simulation of relatively small system dynamics models that can be simulated in a reasonable amount of time. As such, they tend to be ill-suited to storing and executing large models, *i.e.*, those with thousands, or tens of thousands, of equations and array elements.

5 Another product, "DYNAMO" is capable of running large models, but lacks the graphical, model-building capability and other features related to ease of use. Moreover, while this program has advantages for large model definition, the program's simulation engine is based on decades-old programming technologies and is therefore slow as compared to, for example, Vensim, as a platform for running large models. In addition, a  
10 user must have a knowledge of Visual Basic, C++ or a similar programming language to develop a professional-looking interface with DYNAMO. This restriction limits a user's ability to design and create decision support and other software applications that can be used by third parties who do not possess a detailed understanding of how the simulation software itself functions. This is true of Powersim, Vensim, and STELLA as well. While  
15 these programs do provide rudimentary interface building capabilities, users without programming capabilities cannot create professional, packaged applications with these software programs.

There is a growing interest in the use of system dynamics modeling to model business situations and to inform decision making in complex environments. Tools are  
20 needed to facilitate the creation and rapid simulation of large system dynamics models. Such tools should require little or no programming knowledge of the user, have a user-friendly graphical interface, provide user presentation development tools and have a fast simulation engine for rapid modeling of complex systems. In addition, the results of

FIG. 3 illustrates a chart generated in accordance with a preferred embodiment of the present invention.

FIG. 4 illustrates a view of the navigator screen in accordance with an embodiment of the present invention.

5 FIG. 5 provides a view of a dashboard screen in accordance with a preferred embodiment of the present invention.

FIG. 6 shows an exemplary table of the icons within the application toolbar of an embodiment of the present invention.

10 FIG. 7 shows a table of icons for a control toolbar in accordance with an embodiment of the present invention.

FIG. 8 shows an implementation of aspects of the present invention within a computer environment.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 Preferred embodiments of the present invention provide a system dynamics modeling environment with a graphical user interface that allows a model developer to define a model through graphical inputs, for example by selecting icons and dragging them onto a representation of a flow diagram. Most preferably, graphically input data and other information regarding a particular model is stored within a data structure that 20 efficiently organizes the data. Such a data structure is preferred for the organization it provides to model development and because the database organizes and expedites the compilation and execution of the model.

Certain preferred implementations of a system dynamics modeling environment allow the definition of a plurality of groups, with each group consisting of a data set representing a complete flow diagram and capable of being coupled to another group defining a portion of the model. Variables within a group may be defined solely within 5 the group or may be shared with one or more other groups. Thus, when a model including at least two groups is compiled, the compiler recognizes the presence of a shared variable within the two groups and links the two groups together. As with conventional system dynamics programs, it is possible in the preferred modeling environment that individual variables on a layer may contain within them one or more layers of sub-functions or 10 models, with each layer defined by a flow diagram and with variables shared or passed between the layers. The group structure provided in preferred embodiments of the present invention is in addition to such a multilayered structure.

The present invention may be embodied as a computer program product including some or all of the preferred methods that facilitate the construction and simulation of 15 large system dynamics models that might include thousands of equations and array elements. A fast, efficient simulation engine enables certain particularly preferred embodiments of the present invention to combine the ease of use of graphical interfaces with the computational power to simulate large, complex system dynamics models. This is believed to provide a significant advantage to the application of system dynamics 20 methodology to increasingly complex systems while also allowing the end products of modeling to be cost-effectively delivered with familiar and easy to use interfaces.

Preferred implementations of the present invention provide a graphical editor to facilitate the entry of data sets, relationships and structures for very large system

suited to graphical manipulation, such as overall structural layout, and the text-based variable definition editor can be used to define aspects of the model most appropriate to a textual or equation processing interface. A user in the modeling environment preferably automatically creates the variables in graphical form and displays the variables in a 5 separate flow diagram window. Any variables or functional relationships created graphically will show up in the text editor. Once the variables and equations are created, the user has a choice of editing aspects of them and their relationships directly in either the graphical or text editor.

A distinct aspect of certain preferred embodiments of the invention is a model 10 builder "navigator" interface that is most preferably distinct from and in addition to the graphical interface with graphical and text editor capabilities. The "navigator" interface is complementary to the graphical and text editors and provides a model developer with model elements in a hierarchical, tabular or chart-like display so that the developer can easily store, locate, and retrieve major model components, such as groups, variables, 15 plots, equations and macros. The navigator feature allows a developer the ability to view and edit a substantial quantity of data in an organized format. For example, the model developer might use the navigator to view the relationships among a number of variables and access the equation variable dialog boxes that define the relationships among the variables. Such editing can be difficult using a standard, single window graphical 20 interface, and is greatly facilitated using the navigator function. It is particularly preferred that the system dynamics modeling environment provides a navigator interface in addition to the text and graphical editing capabilities.

Certain particularly preferred embodiments of the present invention provide advanced compiler and simulator functions that significantly reduce the time it takes to simulate large models. The use of advanced compiler and simulator functions reduce the time it takes to develop and test models and allow a greater number of tests and model variations, also known as scenarios, to be considered in a practical manner. Another preferred aspect, which is in some regards synergistic with the faster compilation and simulation aspects of some embodiments of the invention, allows the precise identification of scenarios to allow for many scenarios to be run and accurately tracked.

Scenario management capabilities of certain preferred embodiments of the invention enable the specification, storage, and retrieval of a virtually unlimited number of alternative model scenarios.

Other preferred aspects of a system dynamics modeling environment in accordance with the present invention provide a facility for developing user interfaces and a separate facility for defining informative and flexible charts and graphs. A preferred user interface facility provides a "dashboard builder" that enables users without any programming experience to create professional-looking graphical user interfaces for their models. Advanced charting features enable users to create a wide range of two-dimensional and three-dimensional charts with "drill-down" capability. Such charts are, of course, significant to explaining and illustrating the results of simulations.

A number of other design features are worth noting. Preferably, the system provides an "open-enough" architecture so that other languages or applications can be coupled to models or the modeling environment itself to extend the application. For example, one embodiment of the modeling environment directed to this objective

provides a complete implementation of some or all of the aspects of the present invention as a stand-alone ActiveX component. Other applications of the present invention may be coupled to or operated in conjunction with programs written in Visual Basic, Visual C++, Excel or Word Macros, or the Windows (98) Scripting Host. Those of ordinary skill will 5 recognize that the intended outputs and interfaces of the present invention will vary over time and that this list of functionality is representative only.

In conjunction with or distinct from these "usability" interface functions, the design of preferred embodiments of the present invention allows models produced by the modeling environment to be modular so that the environment supports component-based 10 model assembly and distribution. Also in keeping with high quality software design principles, preferred implementations of the present invention support the clear documentation of all model components and their evolution. This allows for the ready modification and distribution of new or replacement component parts of a model as the model is refined or further developed.

15 The term "model" as used herein refers to several related aspects, including the equations and the overall project that is the subject of the model. The definitions in the following list clarify a number of other terms used in the present discussion:

Model	The entire set of information that is used in a modeling project, including simulation specifications, parameter sets, plot instructions, and dashboard layouts.
SDMDB	A System Dynamics Model Database contains some or all of the information for a modeling project. It may also contain all or parts

	of multiple models, model versions, and model variants. An SDMDB may be distributed as a single entity.
Model Structure	The equations and associated flow diagrams that define a model.
Model Version	A specific set of model structure equations that is different from other "versions".
5 Group	A collection of model definition elements including equations and associated flow diagram representations.
Scenario	A scenario is a specific model simulation that is based on a particular version of the model and a particular set of parameter values.
10 Parameter	An input variable that is used in model calculations and whose value helps determine system behavior.
Parameter Set	A collection of parameters that can be invoked or referenced by parameter set name.
15 Model Data	Static information, typically actual system behavior, about modeled system behavior which is used as a point of comparison and is generally not involved in calculating model behavior.

Building and simulating system dynamics models within a modeling environment provided by the present invention preferably involves an iterative process. First, a model is built by defining individual model elements such as variables and the relationships among the variables. This may be done using the graphical editor, a textual editor or, more preferably, both types of editors both sequentially and in cooperation.

Simulation of the model proceeds by defining initial variable states and the length of the simulation time period. The simulation function preferably includes a compilation function to expedite the processing of the model. At the end of the simulation interval, the simulation results can be viewed. A number of tests might be performed on the model 5 at this time. For example, it will often be appropriate to review the values of variables through the system to determine if they are taking meaningless or void values. Also at this point, it is preferred that the simulation results be compared to model data to evaluate the accuracy of the model and the parameters provided to the model. Based on the results of the simulation, the user can then re-specify model variables to modify the results. The 10 process of running a simulation and testing the simulation results against model data is repeated until an appropriate model definition and parameter set is found.

After a model is completely defined, it can be packaged in a form for distribution to end users who will execute the model for different sets of input data to examine the or predict results on the basis of the data sets. The scenario or model is preferably combined 15 with an appropriate set of user interface controls by using the dashboard functionality of preferred aspects of the present invention. In addition, the scenario or model is preferably combined with a desired selection of graphical output displays, adapted to the particular data to be displayed, before the scenario or model is distributed to end users.

20 *System Dynamics Model Databases*

Most preferably, data and other information related to a model are stored within system dynamics model databases (SDMDB's) within the modeling environment. The database structure is a fundamental characteristic of the modeling environment and

model or create a new model, which in turn preferably selects the associated SDMDB or SDMDB's to access. In other embodiments, the modeling environment prompts the developer to identify the initial SDMDB for a session. The developer may open two or more SDMDB's at one time. Scenarios, groups, or elements may be copied or moved 5 between SDMDB's. Some embodiments of standard SDMDB's are write protected and may be used only as the source, and not as the destination, of a file transfer.

In some embodiments of the present invention, provision is made so that an SDMDB may be a library of reusable and independently testable model elements. Preferably, such a database is read-only to the typical user or to users defined below a 10 certain level of access priority. Thus, a modeling environment may include or have access to SDMDB's that are read-only and cannot be altered in a typical modeling session. Preferably, facilities are provided within the modeling environment so that an SDMDB can be generated and made read-only ("locked") to future users or to users that receive a distribution version of the SDMDB. For convenience, if the user or developer 15 closes the modeling environment from within a model, the screen is restored to the condition as of the time of the shutdown. This facilitates resumption of work with minimal delays, which is well appreciated when working on a complex system.

#### *Groups and System Dynamics Models*

20 To aid the model building process, developers can place collections of variables and other model elements inside model groups. The concept of the group is a particularly preferred aspect of the present invention that assists the user in more quickly constructing models, as well as assisting the compiler in more quickly running scenarios. The group

approach is especially useful when constructing large models that consist of many model sectors, each representing a different business focus or useful output of the model. For example, a model may contain a financial sector, manufacturing sector, purchasing sector, inventory sector, etc., and each would be contained within a single group. Unlike system dynamics computer program products in the related art that force the user to place all variables on one or more layers of a single flow diagram, users of a preferred embodiment of the modeling environment can place various model sectors into defined model groups. A model then is a collection of individual but tightly interrelated groups of variables and other model definition elements. When a model is defined within a plurality of groups, each group preferably has defined within it an interface to one or more other groups.

By way of illustration, FIG. 1 might define a single immune system group within a model of disease within the human body. For this embodiment, the screen of FIG. 1 may be a group definition screen and each group within the model would have a corresponding screen that could be called up into the graphical interface by accessing the group for display and or editing. Each of the groups with their associated screens has a name unique within a given model. The group can be accessed, for editing or otherwise, by referencing the name associated with the group in the group definition process facilitated through the screen of FIG. 1. The group definition screen of FIG. 1 shows what might be a substantially complete model of the interaction between the immune system and a pathogen. More complicated or simpler models might be contemplated but are not shown here. Other groups within the larger disease model might include, for example, a group modeling the circulatory system that interacts with the illustrated

immune system group to inform a rate variable for pathogen transport within the immune system group. The complexity of the immune system group shown in FIG. 1 illustrates in part why it is difficult to define a large model within a single flow diagram.

Different groups within a larger model are defined so as to communicate peer to  
5 peer with other groups. This group definition is distinct from another defined and conventionally available capability to define models having layers of complexity incorporate within a give variable or model element.

An embodiment of the present invention provides a computer program product in  
a computer-readable media for use in a computer to build complex system dynamics  
10 models using a plurality of discrete hierarchical system dynamics groups. Each group is a set of interactive model definition elements, and the dynamic relationship among the model definition elements of all groups in the system model defines the structural and quantitative relationship among the variables that comprise the system model. This embodiment preferably includes a means responsive to user selection of a plurality of  
15 system dynamics groups, a means for hierarchically arranging the groups in a system dynamics model structure, a means for copying a variable from a first group to a second group, and a means for defining the dynamic relationship among the groups to describe the effect of changes within the group on the system model and the effect of system changes on the group. In a preferred implementation, the computer program product  
20 simulates the performance of the complex system dynamics model. This preferred implementation preferably includes a means for enabling the groups to dynamically interact during initialization of the system model and as the system model is exercised in a simulation.

Another embodiment of the present invention is a computer program product in a computer-readable media for use in a computer to build a system dynamics group for use in constructing a complex system dynamics model. The group, which has a unique name, includes model definition elements and may have both equation and graphical representations. If the model includes multiple groups, it is preferred that each group includes at least one interface to another group, including at least one reference to a variable in another group.

Preferred embodiments may include a means responsive to user selection of a plurality of model definition elements for a group. A first group might include model definition elements that are selected from the following:

- Variable type;
  - A second group;
  - A variable from a second group; and
  - A flow diagram.
- The group can also include a list of SDMDB's and models to search for additional groups and can further contain simulation specifications.

The variable types that might be defined include:

- Level;
- Rate;
- Auxiliary; and
- Constant.

Of course, this list of variables is not specific to an embodiment in which multiple groups are used to define a given model. These are the variables that might be used in any model, regardless of complexity. Groups provide several benefits, such as:

- Modularization and organization of model definition elements;
- 5     • Support of rapid navigation to reach specific functional areas of the model;
- Support for views of related information;
- Access to reusable equations;
- Automatic flow diagram preparation and maintenance;
- Flow diagram modularization;
- 10    • Easy means for the user to change a group definition for one or more alternative structures;
- Support for distribution of a standard library of Macros;
- Reusable data structures that may be replicated many times within one or more models; and
- 15    • A natural structure for component by component model testing.

Bezier curves are supported for information links and general sketching. These information links and flow links move intelligently when objects are moved. The user may control the shape and path of the curve by using mouse-based drawing tools. In  
20 addition to group objects and links, the user may place text (labels, titles, documentation), boxes, lines, and pictures on the flow diagram.

Display options for each object, link, and optional display elements are controlled using a properties box. These properties include shape, color, style, size, font, and visibility. The user may change the default characteristics for new objects, by object type. The user may also change characteristics for any individual element or selected set of elements. The user may customize the view by including or excluding ghosts, parameters, and constants.

Free-form flow diagrams contain any combination of variables, parameters, or groups and may be constructed by copying all or part of group diagrams. To the extent possible, free-flow diagrams are automatically updated when a variable or link is deleted or when a variable or link is added to a group or variable that is already in the diagram. Causal tracing can be started from a free-form diagram.

#### *Using the Modeling Environment*

Aspects of the present invention might be practiced for the described embodiment of a multiple group model or might be implemented in a different embodiment. Regardless, implementation of a system dynamics model in accordance with the invention may continue after initial database selection by utilizing means responsive to user selection for defining the hierarchical structural relationship of the model definition elements in a group. In practice, this is preferably accomplished in a graphical editor of a type that is familiar and readily implemented by those of ordinary skill in this art.

Referring to FIG. 1, a developer builds a model using the graphics editor 1 by selecting a variable type (level, rate, auxiliary, or constant) from a tool bar 2 and places it on the main flow diagram 3.

A preferred embodiment further includes a means responsive to user selection for defining the quantitative relationship of a model definition element to another model definition element in the group. This might be accomplished in an editing environment that is accessed as part of the graphical editor or it might be accomplished using the text editor. Referring to FIG. 2, once a model variable type is selected and placed on the flow diagram of the graphical editor, the user opens the properties box 50 for that variable. The properties box might have an appearance and functionality like that shown in FIG. 2 and can be used to further define and specify the exact form of the variable. Each variable type has a slightly different properties box as appropriate to how the variable relates to other variables. In most cases, the user specifies an equation 51, or refers to a table or function, describing the relationship between the selected variable and one or more other variables on the flow diagram. The resultant definition is stored within the active SDMDB and is incorporated into the overall system of differential equations that describe the behavior of the system constructed within the modeling environment.

Preferred embodiments might further include means for copying a model definition element from a first group to a second group. This might be accomplished using conventional "cut and paste" graphical editing techniques between two group display windows each like that illustrated in FIG. 1. Alternately, this might be accomplished using the navigator functionality described below. In a still other alternative, a form of model definition copying is accomplished by copying an SDMDB and editing within that copy of the SDMDB.

This preferred aspect of the present invention allows models to be constructed much faster than by conventional methods. In a preferred embodiment, the computer

program product can simulate the performance of the model consisting of at least one group. Once all variables have been specified, the user simulates the model by selecting the simulate command from the menu or toolbar. As will be described below, segmenting the system dynamics model into groups of related elements enhances the 5 ability of the compiler to run system dynamics programs efficiently and quickly. When a simulation is initiated, the compiler examines all the variables and equations and performs checks to ensure that they are properly specified. Once the equation checking is complete, the simulator solves the equations for each time period until the simulator reaches the specified end of simulation. Both the simulation time period (or DT) and the 10 length of the simulation are set by the user. For example, a user may specify a simulation time period of one day, and simulate a model for 365 time periods.

When a simulation run is complete, a developer or user has several options for viewing results. Simulation output can be viewed in either graphical or tabular form. The computer product of the present invention preferably possesses advanced charting 15 capabilities that allow the user to view simulation results in a variety of formats. Users may chose from a range of two-dimensional and three-dimensional bar, column, pie, line and area charts. An example of one form of graphical output is shown in FIG. 3.

Preferred embodiments of the modeling environment include a means of generating a graphical user interface (GUI) responsive to user commands input through a 20 graphical editing tool such as a mouse or other implement that interacts with the graphical editing features of the interface. This GUI can include a means of navigating through the model to a particular group and displaying a view of the state of the group. The GUI, aspects of which are illustrated for example in FIGS. 1-4, includes a screen

displaying the hierarchical structure of the model, a means for selecting a group from the hierarchical structure of the model, and a means for presenting a plurality of views of the selected group's attributes.

- For creating and editing the flow diagrams and models, the program preferably
- 5 provides some standard shapes, such as boxes for levels and valves for rates, shown on the left sidebar of the FIG. 1 display. Additional shapes are provided to offer additional flexibility to the user in developing representations as required. Every variable calculated in a group is preferably placed in the group flow diagram. The user drags and drops to position these objects. Inputs from other groups may be optionally displayed as ghosts.
- 10 Output to other groups may also be optionally displayed. The user may add or delete links using a group flow diagram such as that illustrated in FIG. 1. Further changes as appropriate might then be made through the variable dialog box. Some changes require that the user review and modify the underlying equation or equations and the interface preferably prompts the user or model developer when such a change is made. The
- 15 equation may be modified in the text editor or in the variable dialog box that can be accessed by clicking on the element in the flow diagram.

#### *Macros and Molecules: Reusable Groups*

- Groups may also be used as macros or as molecules, which are groups specifically
- 20 designated as reusable and distributable. Groups designated as macros or molecules contain equation structures that can be used (i) by more than one model, (ii) more than once within a model, or (iii) both.

Macros within the modeling environment of the present invention are fully compatible with existing "DYNAMO" macros. A version of DYNAMO is described in the book by Richardson and Pugh, Introduction to System Dynamics Modeling with Dynamo (Productivity Press) 1981, which is hereby incorporated by reference. Macros 5 are specified by setting the group property for "type of group" to macro. With this specification, the group definition screen lists the calling arguments for the macro in order and indicates whether they are input or output arguments. A macro may contain internal variables not included in the argument list. Macros are invoked in equation mode by using their group name.

10 "Molecules" are extensions of the macro construction. Any thoroughly developed group is suitable for reuse as a molecule. If a group is used as a molecule, it is referred to as a molecule; otherwise, it is simply called a group. Molecules most preferably contain all of the information necessary to make them reusable and commercially distributable. Thus, a molecule contains not only equations and flow diagrams, but also appropriate 15 macros, exogenous data, and parameters. Particularly preferred implementations of the molecule function provide help information that assists the user in using the molecule part of a model.

Molecules connect to the rest of a model by connecting variable names defined within the molecule to variable names defined within the model and the SDMDB for the 20 model. A molecule may be used many times within a model. To function, however, the model must either map every output variable from the molecule to a variable externally defined in the group or use the extended name for all references. A molecule might also be used as an array:

**VARNAME[ RANGE1, RANGE2,...] = MOLECULE.**

This usage will essentially make every output variable in a molecule function as an array.

The reference statement may then be:

**VARNAME [RANGE or ELEMENT] .M VARIABLE.**

- 5 If the molecule contains array elements, each array is preferably assigned one or more additional dimensions:

**VARNAME[RANGE or ELEMENT] .M VARIABLE[RANGE or ELEMENT]**

- Molecule arrays may be used to construct models with predefined model subsets having dimensions varying according to the model or model version. If a model input variable is  
10 an array that uses the same range as a molecule equation, the appropriate element of that input array is preferably used for each affected molecule calculation.

#### ***Macro and Molecule Libraries***

- To facilitate the use of macro and molecule functions, the modeling environment  
15 allows the user to specify a list of external SDMDBs to be searched to find macros and molecules that are not found in the current model. This definitional function within the modeling environment most preferably also allows a user to define an explicit source for each macro or molecule. To the extent possible, the modeling environment functions effectively the same way in all views of the model. The user may select any group in the  
20 navigator or flow diagram by clicking on the group name. A right click opens the Group Actions menu with the selections:

**Open flow diagram - Opens the primary flow diagram window for the selected group.**

Open text editor which opens the text editor view for the group.

Properties Window, describes group properties and other comments.

Insert New Group Before/After, where new groups may be added at any time.

The user is able to create a new group within the model definition of the SDMDB by  
5 entering its name and position. The user may also select a group from the current model  
or from any available SDMDB.

Delete Group, which the user may use to "ungroup" the selected group and to  
assign all of its components to the next higher group.

Replace Version, which the user may use to change the source or version of an  
10 included group. Old versions of groups may be included in the current version.

#### *Compiler Functionality*

Most preferably, the modeling environment provides the ability to build and  
execute simulations of system dynamics models and to make the results available for  
15 review and analysis. This is facilitated in particularly preferred embodiments by  
advantageous aspects of a preferred implementation of the environment's simulator. For  
instance, in a preferred aspect of the present invention, the simulator is an integral part of  
the modeling environment, not a separate program. When a simulation is requested, the  
modeling environment preferably recodes the model equations into tables and structures  
20 that are used during the simulation execution phase. When appropriate, these structures  
are maintained over the life of one or more simulations and preferably support multiple  
executions with minimal overhead. The core of the simulation engine most preferably is  
implemented in performance-coded assembly language to provide high execution speed.

Unlike a traditionally programmed model, a system dynamics model does not contain a sequenced list of instructions. Users are free to type in equations in any order they wish and, by the very nature of the graphical model definition process, equations and variable references will exist within the model (actually, within one or more SDMDB's) 5 in arbitrary order. To generate a simulation, the simulator generally determines a correct sequence of calculations based on the equations existing within the definition of the model. This is a process that is conventionally required of system dynamics software programs in initiating a simulation. Preferred implementations of the present invention, however, provide improved simulator performance by more efficiently performing this 10 process and, most preferably, producing a structure that is itself more conducive to efficient further processing.

The integrated design of a simulator in accordance with the present invention also provides a more flexible simulation environment. "DYNAMO," which is perhaps the most powerful of the conventional system dynamics modeling programs now available, 15 determines a correct sequence of execution during a "compiler" step that precedes simulation. The "DYNAMO" compiler does not support the execution of potentially correct models that involve references within arrays or conditional dependencies. Simulators in accordance with the present invention, on the other hand, support such constructions by providing run-time re-sequencing of equations and variables. Although 20 this technique is commonly used in spreadsheet software, it has previously been thought to provide inadequate performance for large system dynamics models. Particularly preferred embodiments of the present invention address the difficulties of run-time sequencing through the use of individual instruction pointers for each element of each

array as well as the use of relative addressing within the instruction tables through p-code.

The simulator preferably also produces sequenced lists of variables that are to be calculated at a particular time, which can further reduce the overhead of the simulator checking to see if a particular variable has been calculated.

5 Structuring model elements into groups is a particularly advantageous feature of the present invention's modeling environment for enhancing the speed at which simulations can be run. Essentially, by so grouping model elements, certain of the groups can be processed less frequently or even removed from the processing sequence until variables within the group are altered. A system dynamics model typically requires the  
10 execution of a number of equations for a specified number of time periods. A large model might include major segments of equations, or groups, that are not executed during significant portions of the simulation period. "DYNAMO," as an example of a system dynamics modeling system capable of processing large models, simulates all of these equations whether the simulations alter the variables within those groupings or not.

15 To reduce simulation times, the compiler of the present invention is designed to identify the sets of equations that preferably are executed during any given simulation run. In this way, particularly preferred embodiments of a simulator reduce simulation execution time by identifying groups of equations that are 'frozen' during detectable intervals, and therefore need not be executed. In these embodiments, the simulator keeps  
20 track of which variables are active and which are frozen, thereby ensuring the accuracy of simulation calculations while significantly reducing the execution time. Further to these aspects, the modeling environment preferably maintains a list of variables that are known to be uniquely required by a group, which variables are uniquely produced by a group,

each group and variable has a unique identifying serial number, this number is not preserved when copying from one model to another, and thus is of limited usefulness.

Therefore, names are used to determine whether the groups are the same. This generally results in two groups being identified as different if either one has had its name changed.

- 5     Also, if two unrelated groups happen to have the same name in the two models, they will be compared, and their differences shown, just as if they were two versions of the same original group. If any differences are found, a Model Comparison window is shown. This window is a regular application window, not a dialog, allowing it to be moved and resized. This allows the user the flexibility to make changes manually to either model
- 10    while the Comparison window is open.

A group comparison allows the user to compare the contents of a group that exists in both models. It is similar to the Model Comparison dialog, but compares the variables in the two groups. As with groups, names are used to determine whether the variables are the same. Therefore, a variable that has been renamed will show up as both a variable in

15    the source file that doesn't exist in the target file and a variable in the target file that does not exist in the source file.

- The contents of the groups are compared, variable by variable, to see if each variable exists in the other model, and if contents are the same.
  - The variables are defined to be different if any of the following are different:
    - ◊ The number of equations;
    - ◊ The contents of any equation, either regular or Init. This includes different subscripts;
- 20

- ◊ The Units, Legend or Comments;
  - ◊ The Saved checkbox; and
  - ◊ Inside a Macro, the Macro Argument checkbox.
- If any differences are found, a Model Differences window is shown. This window is a regular application window, not a dialog, allowing it to be moved and resized.

### *Generating Scenarios*

The scenario can be a useful tool in analyzing model behavior. Typical modeling analysis involves examination of a number of scenarios. A scenario is a specific set of parameters and a specific model version that produces a certain set of results. For a useful model, a scenario should produce the same results each time it is run. Variable changes that can alter the results constitute a new scenario. A scenario always relates to a specific version of a model and to a specific set of parameter values. The user may create a new scenario by changing the model or the parameters values. Conveniently, the scenario number is assigned in numerical sequence within the SDMDB.

Users have access to features that make it easy to create and save scenarios and models. Using the scenario specification grid, users can easily retrieve model parameters, change parameter values, store parameter sets, and execute and save new scenarios.

Model parameters are accessible in a tree, similar to file folder trees conventionally found in "Windows" applications. Multiple parameters can be selected and changed at once, and these changes can be grouped into parameter sets that can be saved for later use. Model simulation runs, i.e., scenarios, that are executed based on these parameter changes

can be named and are automatically saved by the program. Users can also view a complete listing of saved simulations in the scenario roster. The scenario roster shows all the saved scenarios, a list of parameters that have been changed, and summary output results for each.

5       The user may save the results of a simulation run. The "save" command closes the scenario and freezes all of the inputs required to generate the result. The user may also explicitly discard the results. If the results of a simulation have not been explicitly saved or discarded, the user is preferably forced to choose one of the above prior to exiting or to making changes that would prevent a "save" command from being  
10      successful. The specifications, version, and results are saved by default unless the user or end-user makes an explicit decision not to save the scenario. If the user decides not to save the results or to freeze a specific set of definitions as a scenario, then the scenario definition is not saved.

The scenario list is used to select which scenario to use as a base for other  
15      scenarios. In browse mode, the user can quickly scan the assumptions that distinguish among the various scenarios. The list format may also be used to select scenarios to review. A grid is used to review and select scenarios. The scenario list box may also be used to make a scenario active, which makes it available for comparative analysis with the current scenario. If a user wishes to make an already executed scenario the current  
20      scenario, any work in process must first be discarded.

Scenario numbers are unique within an SDMDB and are assigned starting with the number 1. The default name for a scenario consists of the model name and an ordinal

number sequentially designating the scenario. Alternate names and aliases may be supplied by the user. Scenario numbers are not re-used within a given model, even if certain scenarios are deleted.

The user may change any parameter used by the model. The user may construct  
5 organized sets of parameters to simplify the search for a desired parameter for change. A list of parameters that have been changed during a scenario is always available. A similar list is also available for any past scenario. Parameter sets may be defined independent of a particular scenario. These sets are intended for use when a single group of parameter values is run several times in conjunction either with other groups of parameter values or  
10 with several model variations. Parameter sets are assigned names that identify a particular list of parameters. The user may create multiple versions of a parameter set and specify that a model be executed using each set of values.

Parameter sets are created at the model level. In other words, the parameter set name is unique within an entire SDMDB. Each parameter set contains a set of  
15 parameters and values for those parameters. Parameter set membership, meaning the list of parameter names, may not be changed once the parameter set has been used for a specific scenario. This restriction may be removed if the detail for each parameter is stored for each scenario. Every time a value is changed in a parameter set, a different version of that parameter set is preferably stored under this variation. The version number is simply the number of the scenario that first used that set of values. A specific parameter set is saved for each scenario. This parameter set contains the names of any explicitly used parameter sets, and their versions, as well as any parameter values that were changed for the scenario but that were not explicitly part of a named parameter set.

The results of each scenario are stored in a results area that contains variables and time periods designated for retention. Most interactive results analysis consists of either examining the results of one scenario or of comparing values between several scenarios. By default, the most recently executed scenario is available for review. The 5 user may change the scenario being analyzed and build lists of scenarios to be analyzed.

#### *Output Charts for Scenarios*

Many of the output charts and tables include the results from more than one scenario. For analysis purposes, the user may select any scenario as the current scenario. 10 Any other scenario may be designated as the base scenario. In addition, other scenarios may be designated as active scenarios. The impact of these selections will vary according to the output display method selected.

The user may select a variable to display by clicking on it anywhere within the model structure (navigator, flow diagram, or text editor). By right clicking within the 15 model structure, several options appear including the display of the default plot.

The program includes a number of standard plot capabilities, including line plots, scatter diagrams, pie charts, and bar charts, both vertical and horizontal. A default plot method is always available for graphical display of any variable. The initial default type is a line chart that shows the values of that variable for the current scenario compared to 20 values for any other scenarios that may exist and that have been activated for this purpose. If the user wishes to see an alternate presentation of the information, a right-click within the plot window will allow the user to change to an alternate format or to a

customized chart. The user may also change the definition of the "default" plot. The plot window remains active until the user explicitly closes it.

Thus, the user may have many plots on the screen at one time. The user may further specify that all actions are to be interpreted as analysis. In such a case, the left-  
5 click of the mouse on any variable causes the default plot to be displayed immediately.

Tabular output may be viewed in much the same way as charts. The tables may be selected from standard comparative displays or from custom tables. The user can specify chart or tabular output by using the "define output" features. Each plot produces an output window that can be configured, sized, and placed using a standard Windows  
10 interface. The user may also specify algebraic expressions whose results are displayed.

Once a plot, chart, or tabular report has been configured, the user may elect to save the definition for that report. The specification may include the option to use the variable current as of the run-time or to use the original variable value set at the time the model was built. Once a custom plot is defined, it is available through a list box when  
15 the user right clicks on an appropriate item. These plot definitions may be associated with a specific group and are displayed in the navigator tree. The plot specifications preferably include:

- Line chart specification;
- Bar chart specification;
- 20 • Pie chart specification;
- Scatter diagram; and
- Table output specification.

Users also have the option of saving groups of plots, or "plot sets." A single plot set that contains multiple plots can be created, saved and retrieved by the user. The "click-to-trace" command combines aspects of the click-to-plot, rapid mode, and tree diagrams. Click-to-trace allows the user to trace chains of cause-and-effect, or drivers, 5 very quickly. With click-to-trace mode selected, every click on a variable will result in a plot of that variable and its inputs (the drivers). Clicking on one of the drivers will result in a further trace. With click-to-trace mode set, the user may also view a text box that displays the corresponding equations. This box is cumulative; it includes the starting point and any number of levels.

10 Any chart or report may be moved to "POWERPOINT" or "WORD" or many other Windows products by either copying and pasting or by the drag-and-drop technique. Scenario results may be directly output in spreadsheet form, for instance into a format compatible with "EXCEL". These results will use each saved variable as a row and each "save per" as a column. Output properties may be used to control labels and  
15 formats.

#### *Variable Dialog Boxes*

Equation Syntax: The equations specified for levels, flows, and auxiliary variables use the following syntax:

- 20 • The calculated variable (element, array, or vector) is identified in the name box.  
• Time references are not included.

- White space and parentheses may be used to the definer's content.

Level: The variable definition box for a level provides a very structured format for changes in level. Most preferably, every input and output is required to be assigned a name. Flow equations may be modified in this window. Alternately, the user can double 5 click to move to a detailed flow screen. Changes in the flow screen automatically update the equation view in this window. Levels are specified with in and out flows, by name. Model variables are created for each flow referenced, unless the variable already exists. If the level is an array, the initial value specification may switch to another screen. The variables used by section will provide an initial view into model structure.

10 Flow: Flow equations may be associated with specific source and destination levels.

Tables: Table variables may be specified using the graphical table changer or they may be displayed in a matrix format.

15 Variable subscripts will use a graphical tree control for specifying and displaying subscript families (i.e., arrays) and elements to which the subscripts are applied. When the user wishes to apply a subscript, the user selects the subscript using the variable dialog box extension pad. Once applied, the family display will show the subscript in the graphical tree box for the family. It will be assumed that both sides of the equation have this subscript. If the user wishes to specify a different equation for one or more elements 20 of the subscript families that apply to the variable, the user selects a new equation (using the index control), selects which elements the new equation will apply to using the graphical tree control, and enter the equation to be applied. Numerous equations may be

specified in this fashion. If the user wishes to specify equations that have different subscripts on the left and right side of the equation, the explicit method must be used.

#### *Automated Simulation Control*

- 5       Automated simulation control refers to various analysis activities that consist of running a number of simulations and analyzing the results. Each of these analysis sessions begins with a definition of the simulations to run and of the reports or outputs to produce. Special analysis calculations may be specified for each run and for comparisons between runs. The setup information for each automated session is saved for future  
10      review and for possible reuse. The major types of automated sessions are:
- Sensitivity Analysis (also referred to as "grid search");
  - Goal Seeking / Optimization;
  - Monte Carlo (Stochastic);
  - Driver and Potentiator Identification; and
  - 15      • Confidence Analysis.

#### *Sensitivity Analysis*

- Sensitivity analysis provides the ability to execute the model a number of times in order to evaluate the impact of changing one or more decisions or assumptions.  
20      Sensitivity analysis begins with a dialog box that prompts for definition of what actions to perform. The initial screen includes the model version(s) to use and the input variable(s) to be applied. Each selected version or variable is applied independently of other versions or variables. Therefore, if two model versions are selected and run against

variables with three alternate values, the automated simulation controller will run six simulations. The user may specify up to eight variables and up to ten values per variable.

For each variable selected for sensitivity analysis, the user may specify a starting value, ending value, and increment. The user may also specify values or percent changes.

- 5 For table functions or for time series data, the user may specify values or time series data. In each case, the user may enter a description for each selection. Results of the sensitivity runs may be compared by displaying the values for one or more outputs presented with the assumptions and decisions that caused those results. These tables may be sorted in ascending or descending order by results. A number of standard graphs are available to
- 10 provide a visual comparison of the sensitivity scenarios. Any saved variable may be selected for BEST-WORST-MEAN-MEDIAN output. This type of analysis may also be used between any "slice" of the output.

#### *Goal Seeking and Optimization*

- 15 Automated goal seeking and optimization (maximize or minimize) functions are supported by means of a multiple iteration controller. The analyst is able to select an output variable and to designate one or more input variables or parameters that will be changed methodically in order to reach a solution, or at least an approximation. The analyst may specify ranges for each input, and acceptable ranges for additional output
- 20 variables (*i.e.*, "Maximize year profits but maintain existing staff levels"). The setup screen for this type of iterative processing allows the user to limit the total number of iterations or the total amount of clock time.

The best results are saved during the process. Following each iteration, the best fit iteration display is updated. A running count of total attempts is also displayed, as is the average run time. A variety of algorithms are provided that allows for optional "pruning" or identification of optimal results.

5

#### *Monte Carlo Simulation*

Monte Carlo simulation allows the user to specify one or more inputs that vary "randomly" according to an assumed probability distribution. The program preferably supports several commonly used distributions. The model can then be run many times to 10 assess the distribution of results given the assumed distribution of inputs. This can provide useful information for risk assessment. In order to use Monte Carlo simulation, the user preferably specifies the input variable(s) to use, what distributions to apply, and which output variables to track. A detailed log of the results of each simulation may be reviewed in tabular form. Selected output variables may be viewed with mean, median, 15 maximum, minimum, standard deviation, and other statistical measures.

#### *Driver and Potentiator Identification*

Embodiments of the present invention provide algorithms that seek to identify important non-obvious relationships. For any given variable, the inputs that generate 20 changes in behavior are identified and ranked. "Potentiators" are defined as multiple factors that, when changed in conjunction with each other, generate a much larger impact than the same level of changes in individual parameters. The program provides the ability to search for potentiators among the input parameters. The user specifies the

output variable that is being tracked, and the program will automatically execute the model many times with variations of parameter values. The output of this search is a table listing of the changes in output and corresponding inputs.

## 5    *System Architecture*

FIG. 8 illustrates a further aspect of the present invention in which either the modeling environment or a model, whether in development or in a finished form after distribution, may be provided within a computer system 200. The illustrated computer system 200 includes a main system 202 including a first long term memory 204 that might include a hard disk drive, optical storage, solid state storage or any practical memory for storing the programming environment and various versions of models and other data sets related to the use of the environment or models. The main system includes a processor 206, which in some embodiments is a single processor and in other embodiments may be an array of processors configured to process models, equations and other model elements in parallel. It should be appreciated that the illustrated embodiment of the main system may not be a single computer system but might also be a number of computer systems distributed over a network or in other fashion.

The main system includes a second memory 210, which functions as a workspace either for the modeling environment or a model such as when a distributed model is being simulated by an end user. The second memory may include a RAM or other solid state storage workspace and portions of hard disks, as appropriate to include the proper amount, speed and accessibility of memory for the environment, programs and models. During operation of the modeling environment, some or all of an SDMDB 212

is preferably stored in the second memory as the active SDMDB for the modeling session. Shown in the SDMDB 212 are two groups that are defined within the SDMDB, one of which might be the simulation definition group. As is preferred in many embodiments of the present invention, the simulator 214 and integrated compiler 216 are 5 present in or accessible from the second memory 210 because these program elements are integrated parts of the modeling environment.

Attached to the main system 202 is at least one display 220 that might be used in either developing a model or in running a simulation. Depending on the particular functions accessed, an appropriate one of the interfaces 222 discussed above is provided 10 on the display 220. Of course, the interface elements 222 shown on the display 220 may only be aspects of the overall interface, some of which may include functionality that is defined, stored and operated within one or more portions of the main system 202. Also attached to the main system 202 is an I/O facility that may include a wide range of input devices, such as a mouse or other pointing device, a keyboard, a network connection and 15 one or more external data storage devices, and a wide range of output devices, including a colored printer appropriate to generating hardcopy output from the graphical output facilities of the modeling environment.

Although the present invention has been described in detail with reference only to the presently-preferred embodiments, those of ordinary skill will appreciate that 20 various modifications can be made without departing from the invention. Accordingly, the invention is defined by the following claims.

**What is claimed:**

1. A computer program product in a computer-readable media for use in a computer to build a system dynamics group within a complex system dynamics model, the group including model definition elements, the computer program product comprising:
  - 5 means responsive to user selection of a plurality of model definition elements for the group;
  - means responsive to user selection for defining the hierarchical structural relationship of the model definition elements in the group;
  - means responsive to user selection for defining the quantitative relationship of a model definition element to another model definition element in the group; and
  - 10 ...means for copying a model definition element from a first group to a second group.
2. The computer program product of claim 1, wherein the group is a first group and
  - 15 the model definition elements are selected from the group consisting of: variable type, a second group, variable from the second group, parameters, exogenous variables, plots, dashboards, and flow diagram.
3. The computer program product of claim 2, wherein the variable type is selected
  - 20 from the group consisting of: level, rate, auxiliary and constant.

4. The computer program product of claim 1, wherein the program product simulates the performance of the group, the computer program product further comprising means for enabling the model definition elements of the groups to dynamically interact during initialization of the group and as the group is exercised in a simulation.

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5. A computer program product in a computer-readable media for use in a computer to build a complex system dynamics model using a plurality of discrete, hierarchical system dynamics groups, each group a set of interactive model definition elements, wherein the dynamic relationship among the model definition elements of all groups in the system model defines the structural and quantitative relationship among the variables that comprise the system model, the computer program product comprising:

means responsive to user selection of a plurality of system dynamics groups;

means for hierarchically arranging the groups in a system dynamics model structure group; and

means for copying a variable and its properties from a first group to a second

means for defining the dynamic relationship among the groups to describe the effect of changes within the group on the system model and the effect of system changes on the group.

15  
20 6. The computer program product of claim 5, wherein the program product simulates the performance of the complex system dynamics model, the computer program product further comprising means for enabling the groups to dynamically interact during initialization of the system model and as the system model is exercised in a simulation.

7. The computer program product of claim 5, further comprising means for generating a graphical user interface responsive to at least one user command.

5 8. The computer program product of claim 7, further comprising means of navigating through the model to a particular group and displaying synchronized views of the state of the group, wherein the means for navigating include means for displaying the state of the group in response to commands received from the graphical user interface means; and the graphical user interface means comprises:

10 a user viewing screen displaying a hierarchical structure of the model;  
means for selecting a group from the hierarchical structure of the model;  
viewing tracing drivers and "where used" drivers, and  
means for presenting a plurality of views of the selected group's attributes.

15 9. The computer program product of claim 8, wherein the group attribute views are selected from the group consisting of: variables, diagrams, dates and outputs.

10. The computer program product of claim 8, further comprising a means for selecting a model definition element and displaying all of the occurrences of the element  
20 in the model.

11. The computer program product of claim 7, further comprising a means of designing a customized graphical user interface for simulating a model in accordance with a first predetermined set of model definition elements, the set of model definition elements having at least two variables that dynamically interact.

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12. The computer program product of claim 11, wherein the means of designing the customized interface further comprises

means responsive to user selection of customized simulator controls and for displaying them;

10 means responsive to user selection of functional linkages of each simulator control to a model definition element; and

means responsive to user entry of an initial state of each variable in the model definition element and for displaying a result of the custom simulation.

15 13. The computer program product of claim 11, wherein the customized simulator is a first customized simulator and the set of model definition elements is a first set of model definition elements, the program product further comprising means of designing a second customized interface for simulating a model in accordance with a second predetermined set of model definition elements, the second set of model definition elements having at least two variables that dynamically interact, where the model definition elements of the second customized interface include a variable that is not present in the model definition elements of the first customized interface.

14. The computer program product of claim 6, wherein the dynamic result of the interaction of the groups can be stored on and retrieved from a readable writeable storage device.
- 5 15. The computer program product of claim 6, wherein the complex system dynamics model can be stored on and retrieved from a readable and writeable storage device.
16. A method of building a complex system dynamics model using a plurality of discrete, hierarchical system dynamics groups, each group having a set of dynamically interactive model definition elements, wherein the dynamic relationship among the model definition elements of all groups in the system model defines the structural and quantitative relationship among the variables that comprise the system model, the method comprising:
- 10       configuring a system dynamic structure to be modeled by selecting a set of system dynamics groups;
- 15       hierarchically arranging the groups in a structure;
- 20       copying a variable from a first group to a second group; and
- 25       defining the dynamic relationship among the groups to describe the effect of changes within the group on the system model and the effect of system changes on the group.

17. The method of claim 16, wherein the step of selecting includes assigning a first group a name and assigning a second group a name, and wherein a graphical first flow diagram display shows the first group and does not show the second group.

5 18. A method for identifying model potentiators and defectors defined as multiple factors that, when changed in conjunction with each other, have a comparatively larger impact than the same level of changes in individual ones of the multiple factors, the method including steps of varying the multiple factors.

10 19. A system dynamics modeling tool, including:

a graphical interface for inputting a flow diagram representation of one or more system dynamics model elements;

a definition facility, linked to the graphical interface and accessible from the flow diagram representation, for defining one or more characteristics of a model element; and

15 a navigator interface, distinct from the graphical interface, adapted to display a first plurality of model elements in at least one view of the interface and allowing editing of one or more characteristics of each of the first plurality of model elements.

20. The tool of claim 19, wherein the definition facility is accessed from the graphical interface using a pointing device in conjunction with a displayed flow diagram.

21. The tool of claim 19, further comprising an end user interface development facility capable of providing graphically operable tools for adjusting a value of at least

one parameter and for selecting a type of display illustrating time variations in at least one model element.

22. The tool of claim 19, further comprising an end user interface development facility capable of providing an end user display illustrating time variations in at least one model element, the end user display automatically provided with a drill down function allowing an end user to display an underlying definition of the model element by selecting an aspect of the end user display.

10 23. The tool of claim 19, wherein the graphical interface further comprises a group definition screen, the graphical interface accepting input through the group definition screen to define a first group and assign the first group a name, the graphical interface accepting input through the group definition screen to define a second group and assign the second group a name.

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24. The tool of claim 19, wherein the graphical interface is adapted to accept input to define a first group and assign the first group a name, and to define a second group and assign the second group a name.

20 25. The tool of claim 24, wherein the graphical interface is adapted so that a flow diagram display of the first group shows an input from the second group as an indication of a common variable shared between the first and the second group.

26. The tool of claim 25, wherein the input is represented in the flow diagram in a manner visibly different from like relationships entirely within the first group.

27. The tool of claim 19, wherein the tool is stored on computer readable media.

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28. The tool of claim 19, wherein the first plurality of model elements and the one or more characteristics of the first plurality of model elements are stored in a system dynamics model database.

10 29. The tool of claim 19, wherein the first plurality of model elements and the one or more characteristics of the first plurality of model elements represents a first group and wherein the navigator interface is adapted to display characteristics of a second plurality of model elements for a second group in at least a second view of the navigator interface.

15 30. The tool of claim 29, wherein the first group and the second group are identified by distinct flow diagrams in the graphical interface.

31. A system dynamics modeling tool, including:
  - a graphical interface for inputting a flow diagram representation of one or more system dynamics model elements; and
  - a definition facility, linked to the graphical interface and accessible from the flow diagram representation, for defining one or more characteristics of a model element,
    - 5 wherein the graphical interface is adapted to accept input to define a first group and assign the first group a name, and to define a second group and assign the second group a name,
    - wherein the graphical interface is adapted so that a flow diagram display of the
  - 10 first group shows an input from the second group as an indication of a common variable shared between the first and the second group, and
  - wherein the input is represented in the flow diagram in a manner visibly different from like relationships entirely within the first group.

35. A system dynamics modeling tool, including:

a graphical interface for inputting a definition of a system dynamics model, the interface adapted to receive variable definitions and equation definitions that define the model; and

5 a compiler receiving as input a plurality of variables and a plurality of equations within the model and operating on the variables and the equations to ensure that a definition exists for each of the variables and equations in the model, the compiler generating an error message if a variable or equation is undefined.

10 36. The tool of claim 35, further comprising a simulator to solve equations at each of a plurality of defined time intervals.

37. The tool of claim 36, wherein the simulator solves selected equations at fewer than the plurality of defined time intervals.

15 38. The tool of claim 36, wherein a time interval and a length of simulation are stored in a memory and wherein the simulator retrieves the time interval and the length of the simulation from memory and simulates the model at the plurality of defined intervals for the length of the simulation.

20 39. The tool of claim 35, wherein the compiler examines the variables to identify an occurrence of a duplicate variable definition and to generate an error message in response to the occurrence of a duplicate variable definition.

40. The tool of claim 39, further comprising a variable reordering facility receiving as input a list of equations operating on variables and reordering at least one of the listed equations to cause a first equation that is solved to generate a value of a variable to be 5 executed before a second equation that uses the variable in a calculation, where the first equation followed the second equation in the list.
41. The tool of claim 40, wherein the graphical interface generates a flow diagram representation of the model, the graphical interface further comprising a definition facility 10 accessible from the flow diagram representation, the definition facility adapted to receive at least some of the variable definitions and equation definitions.
42. The tool of claim 35, wherein the compiler searches for a functional relationship between a first and second variable defined as a table function mapping first variable 15 values onto second variable values and, when such a table function is found, the compiler generates a segmented linear approximation of the table function relating the first values to the second values.
43. The tool of claim 42, further comprising a simulator to solve equations at each of 20 a plurality of time intervals, the simulator adapted so that, when a segmented linear approximation is present, the simulator calculates the segmented linear approximation at one or more time intervals.

44. The tool of claim 42, wherein the compiler generates segmented linear approximations by cubic spline interpolation.

45. A system dynamics modeling tool, including:

5 an interface for inputting a representation of one or more system dynamics model elements;

a definition facility, linked to the interface, for defining one or more characteristics of the model elements, the definition facility adapted to receive variable definitions and equation definitions relating variables to other variables;

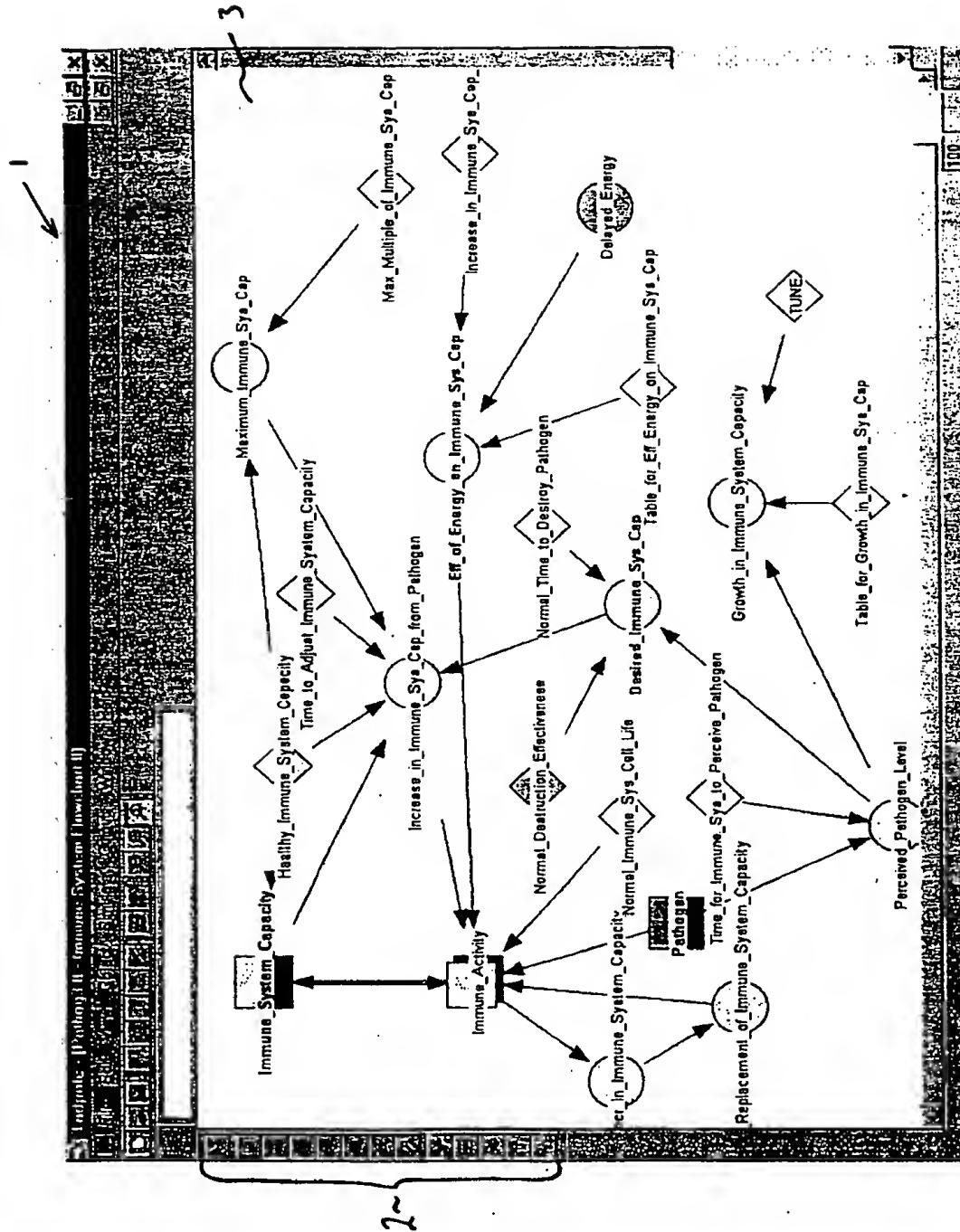
10 a compiler receiving as input a plurality of variables determined by operation of a corresponding plurality of equations, the compiler operating to identify a first subset of the plurality of variables that do not vary in a given time and to identify a corresponding first subset of equations

15 a simulator to solve equations at each of a plurality of defined time intervals over a length of a simulation, the simulator calculating a second subset of equations at each of the plurality of time intervals and calculating the first subset of equations at fewer than the plurality of time intervals.

46. The tool of claim 45, wherein the graphical interface is adapted to accept input to define a first group and assign the first group a name, and to define a second group and assign the second group a name, and wherein the graphical interface is adapted to show a first flow diagram display for the first group and to show a second flow diagram display for the second group.

47. The tool of claim 46, wherein the first subset of equations are the equations of the first group and the second subset of equations are the equations of the second group.

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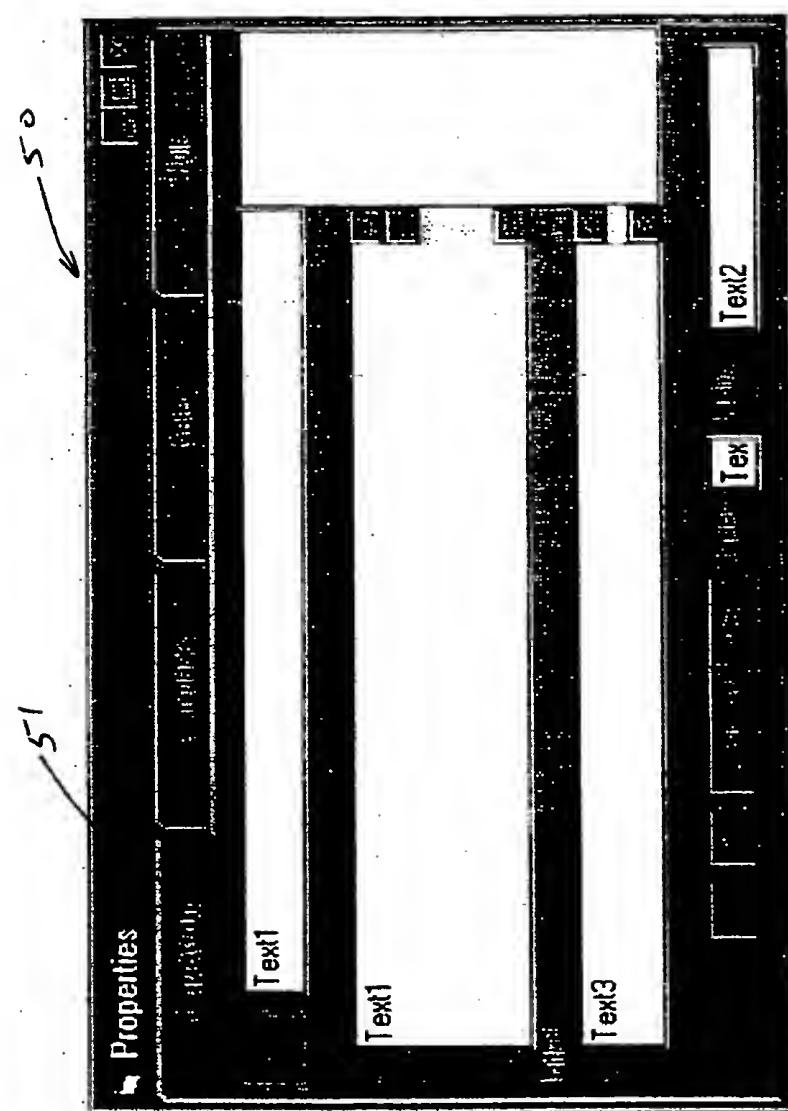


FIG. 2

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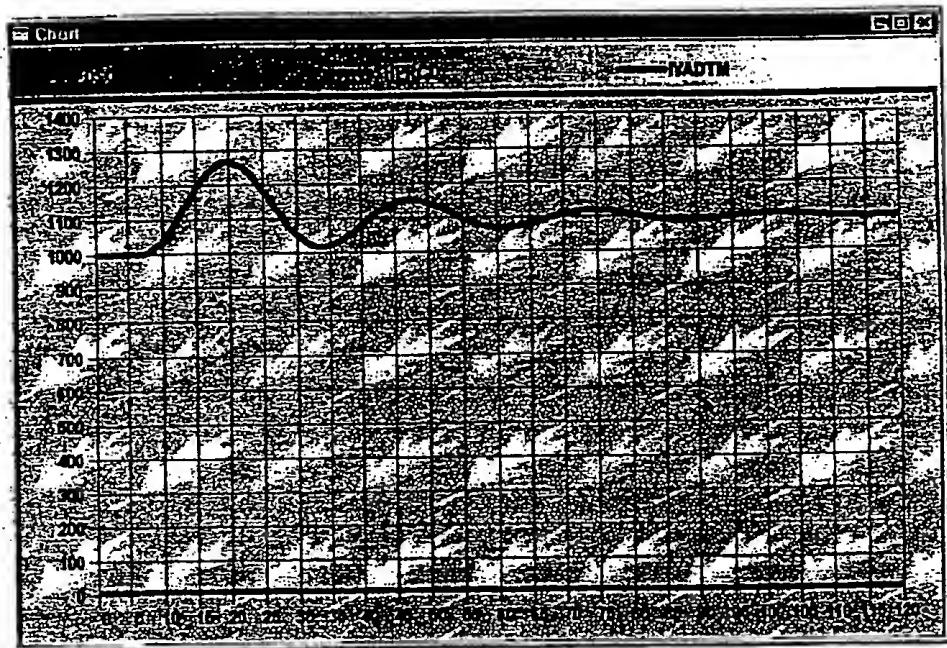


FIG. 3

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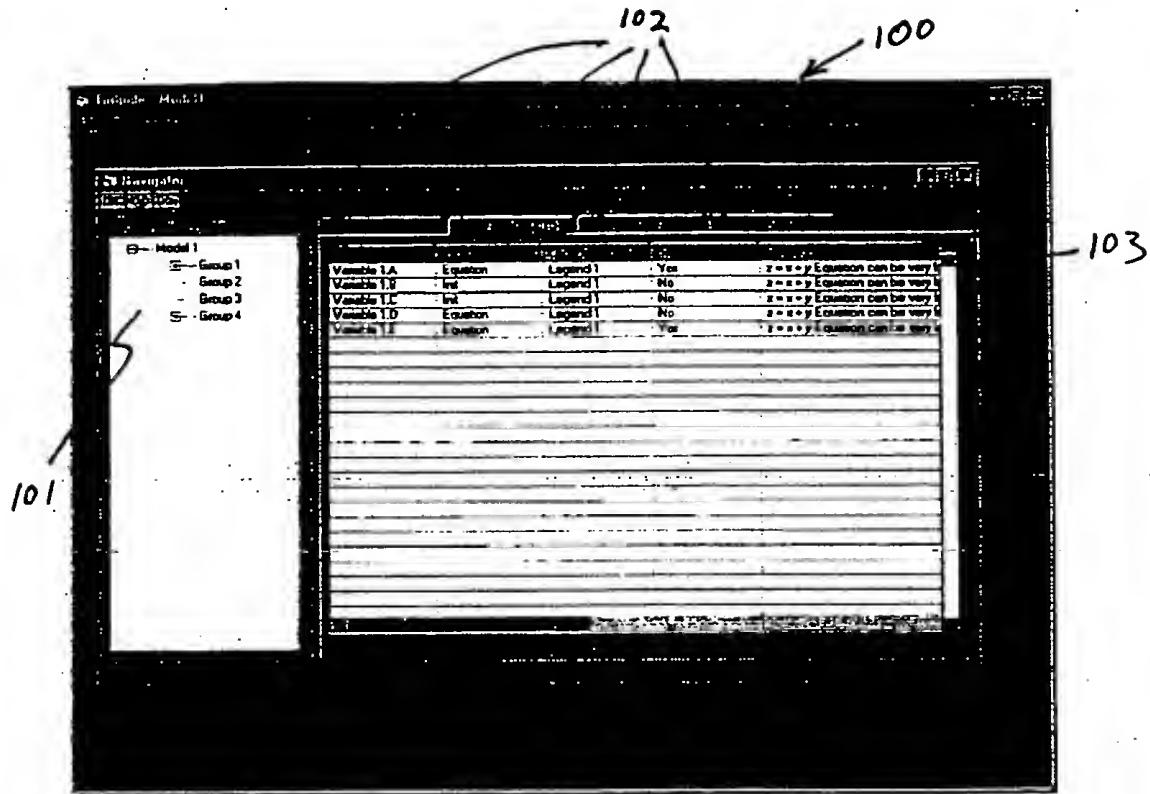


FIG. 4

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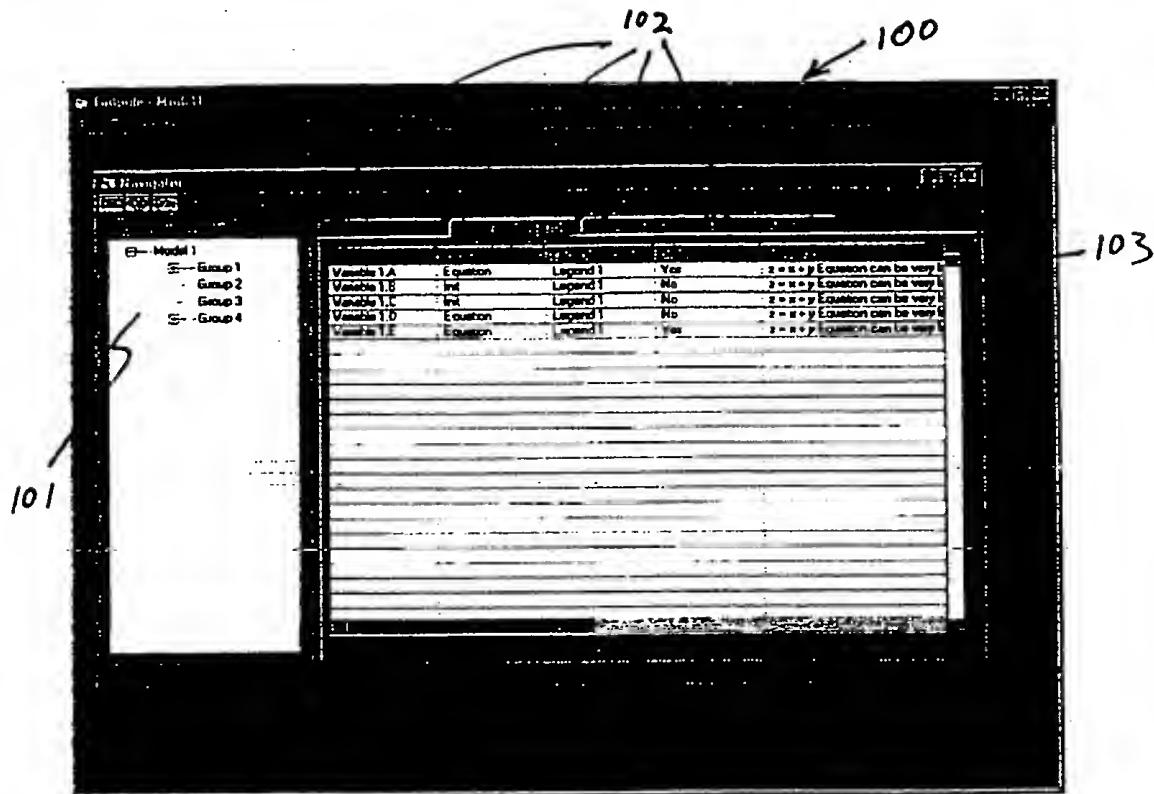


FIG. 4

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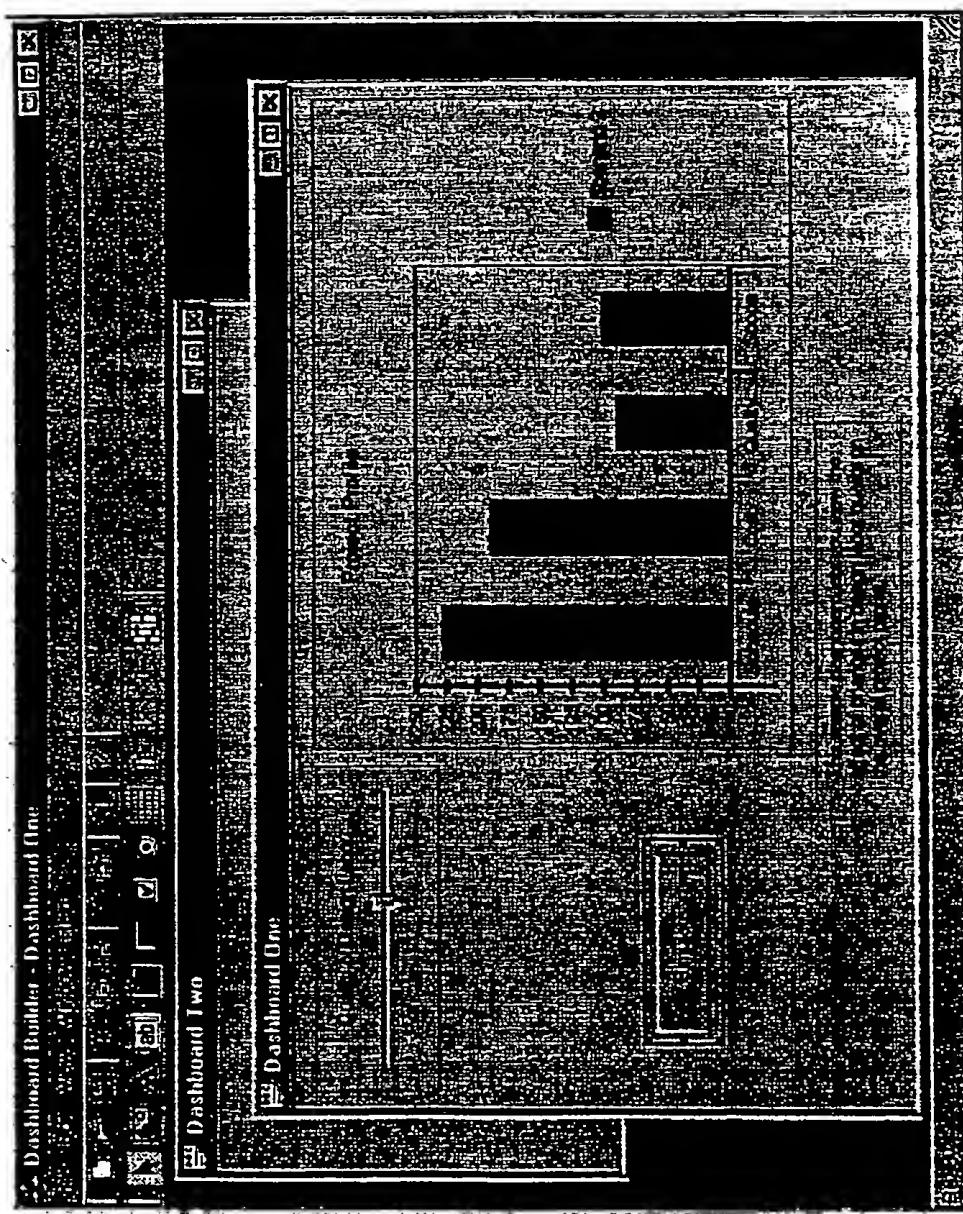


FIG. 5

Icon	Action
	Create a new dashboard document
	Open a dashboard document
	Save the active dashboard document
	Cut
	Copy
	Paste
	Show properties for selected control
	Show properties for active dashboard
	Show "Insert Control" Dialog
	Show "Insert Object" Dialog
	Toggles between design and test modes
	Show Help

FIG. 6

Icon	Action
	Select or Resize an existing control
	Drag out a new Graphic Control
	Drag out a new Static Text Control
	Drag out a new Edit Text Control
	Drag out a new Group Box
	Drag out a new Push Button
	Drag out a new Check Box
	Drag out a new Radio Button
	Drag out a new DB Table Grid
	Drag out a new Navigator Tree
	Drag out a new GTC
	Drag out a new Slider
	Drag out a new Gantt

FIG. 7